

A Database For Propagation Models

Anil V. Kantak, Krisjani Suwitra and Chuong Le

**Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109.**

1.0 Introduction

To design a telecommunications system, the systems engineer usually needs at least a few parameter values governing the radio wave propagation through the channel associated with the system. To obtain the definition of the channel, the systems engineer generally has a few choices. A search of the relevant publications such as the CCIR's, NASA propagation handbook, etc., may be conducted to find the desired channel values. This method may need excessive amounts of time and effort on the systems engineer's part and there is a possibility that the search may not even yield the needed results. Another possible method to define the channel is to find other similar systems and use the needed values from them for the design of the present system. This method has the obvious disadvantage that very rarely two telecommunications systems are exactly alike, and hence, the values to be transported to the system design at hand may not produce correct results.

The best method of obtaining the pertinent parameter values is to generate them using the propagation models describing the channel in question. This method is by far the best because the parameter values are produced for a particular set of system requirements. The obvious disadvantage of this method is that the systems engineer must resort to programming the propagation phenomena models of interest to obtain the parameter values to be used in the system design. The systems engineer must either be a skillful computer programmer or must hire a programmer. This, of course, increases the cost of the effort; an increase in cost due to the inevitable programming effort may seem particularly inappropriate if the data generated by the experiment is to be used to substantiate the already well-established models, or a slight variation thereof.

The National Aeronautics and Space Administration's (NASA's) Propagation Program supports academic research that models various propagation phenomena in the space research frequency bands. NASA supports such research via schools and institutions prominent in the field. The products of these efforts are particularly useful for telecommunications systems engineers and researchers in the field of propagation

phenomena. To help the researcher and the systems engineers, it was recommended by the conference participants of NASA Propagation Experimenters (NAPEX) XV (London, Ontario, Canada, June 28 and 29, 1991) that a software should be produced that contains propagation models and the necessary prediction methods of most propagation phenomena. Moreover, the software should be flexible enough for the user to make slight changes to the models without expending a substantial effort in programming.

2.0 Properties of the Propagation Database

The Propagation Model Database described here creates a user friendly environment that makes using the database easy for experienced users and novices alike. The database allows sufficient freedom for users to custom fit the propagation phenomena model of interest to their requirements. The database is designed to pass data through the desired models easily and generate relevant results quickly. The database already contains many propagation phenomena models accepted by the propagation community and every year new models are added to it. Only minimal computer operations knowledge is necessary to run the database.

The major sources of models included in the database are the NASA Propagation Effects Handbook or the CCIR publications, sometimes they are taken from other publications such as the IEEE Journal etc. Every model included in the software contains a reference to the document from which the model was obtained, and if desired, a brief description of the model itself can be brought up on the screen or even printed. Also, when applicable, the related model names to the active model are also indicated. The parameters of every model in the database are shown explicitly, and the units of the parameters are defined completely so that the user does not have to invest time investigating them. Wherever possible, to make the use of the model obvious to the user, default values of the parameters are given. The default values are generally values that are used most frequently with the model; the users are free to change them to more appropriate ones for their own case. One possible use of the default values is to compare the already known results using the default values with the newly obtained values in an experiment.

Sometimes a propagation phenomenon model may have many formulas, numbers generated by one formula are used by the next, and so on until the final result is generated. In such cases, to include them as single step models in the database would make their use and understanding quite difficult, if not impossible. To avoid this inconvenience, such models are broken down into several logical steps as appropriate, and parameters as well as outputs of each step are described in detail one step at a time. The software makes use

of the extensive charting capabilities offered by the Microsoft Excel software to produce charts for the model under use and the users can use these charting capabilities to change any attribute of the produced chart. Where feasible, the actual charting process is made transparent to the user and involves the user only when a choice must be made between the possible inputs or outputs.

The database also allows the user to make changes, within some guidelines, to the model being run. The main restriction is that the user may make changes in mathematical functions and operations used in the model using only already existing input parameters of the model; no new definitions of parameters will be permitted. In general, this restriction is a reasonable restriction and the user can test slight variations of the existing model generated by utilizing different mathematical functions and operations than the original model.

Every model in the database has the same operating procedure and instructions, thus the user needs to learn the procedure for only one model in order to use the entire database effectively. All the necessary precautions to ensure the correct use of the database are incorporated in the program. When incorrect inputs are made or when an action conflicts with the general directives of the model at hand, the user is alerted with a warning, and where possible, suggestions are made to correct the input.

User friendly procedures are used to call the available mathematical functions of Excel software, such as curve fitting, statistical analysis, etc. This allows the user to apply these functions to the data whenever needed.

3.0 Software Selection to Host the Propagation Database

In the early stages of the software development, a study was conducted to evaluate the advantages and disadvantages of currently available compiler-based programs versus spreadsheet programs for hosting the propagation database software. The results of this study indicated that between the spreadsheet/database software and the compiler based software available then, because of its very nature of dealing with data in columns without extra effort, the spreadsheet software will easily create a product such as the Propagation Models Database.

Of the many commercially available spreadsheet programs at that time, Microsoft Excel was selected to host the Propagation Models Database. Excel provides an extensive list of the database and mathematical functions necessary to implement the propagation models. Excel also has excellent charting capabilities that include many versions of two-and three-

dimensional charts, which can be easily used or automated using the macro language. Excel also offers the dialog box utility, which can be effectively used for input and output functions of the Propagation Models Database. Another notable advantage of Excel is that it can call any executable programs written in C, which is a compiler-based program. This arrangement is ideal because it combines the advantages of a spreadsheet environment with the speed of the compiler-based software for number-crunching purposes.

4.0 Software and Hardware Requirements

To run the Propagation Models Database, Microsoft Windows 3.1, and Microsoft Excel 4.0, or later versions are required. A personal computer equipped with an 80386 cpu, accompanied by its 80387 math coprocessor chip, with at least 4 Mbytes of RAM, is required to run the software. The clock speed should be at least 20 MHz. An 80486 or Pentium based system with higher clock speed is preferable. Any other computer (e.g., an 80286-based PC) with sufficient RAM will run the software, however, it will be very slow.

For the Macintosh version of the database, a Macintosh II ci or better computer accompanied with its coprocessor chip and having at least 4 Mbytes of RAM is needed to run the software. The clock speed should be at least 20MHz.

It is recommended that a color monitor be used so that the charting can be done more effectively. Also, needed is a hard disk with at least several megabytes of storage space available for the software.

5.0 The Propagation Database

The Propagation Database is divided into six categories: the Ionospheric models, the Tropospheric models, the Land Mobile Systems models, the Effects of Small Particles models, the Rain models, and the Radio Noise models. These six categories are further divided into subcategories to include all the models to be housed in the software.

Ionospheric Models:

Tropospheric Models:

Index of Refraction Profile Model, Gaseous Attenuation Model, Refraction and Fading Model, and Scintillation Model

Mobile Satellite System Models:

The mobile satellite models are subdivided into 'Land Mobile System Models' and 'Maritime Mobile System Models'.

Land Mobile Satellite System Models:

Attenuation Frequency Scaling Model, Cumulative Distribution of Fade Duration Model, Cumulative Distribution of Non Fade Duration Model, Diffusely Scattering Model, Diversity Improvement (Tree Shadowing) Model, Empirical Regression Models, Empirical Roadside Shadowing Model, Faraday Rotation Model, Fresnel Zones, Frequency Reuse Using Orthogonal Polarization Model, Raleigh Model, and Reflection Coefficient Model.

Maritime Mobile Satellite System Models:

Fading Due to Sea Reflection Model, and Interference Due to Reflection Model.

Effect of Small Particles Models:

Cloud Model

Rain Models:

CCIR Model, COMSAT Model, Global Model, Depolarization Model, and Site Diversity Model.

Radio Noise Models:

Noise Model

The access to any model is carried out using Excel's dialog box user interface. Each dialog box is divided into six distinct areas to help the user to provide the inputs easily.

The six areas of the dialog box are described below. The first area is used to provide general information about the model selected by the user. This step describes any particular conditions required by the model, the parameter ranges as well as the number of steps the model has, and so on. The second area is used to display formulas describing the model selected. The formula can be modified by the users to a certain extent using legal expressions in Excel. Once the formula is created, the software will use this formula for the current run only. Loading the software again will bring back the original formula. The third area is the parameter definition area, where all the parameters of the model are defined appropriately. The fourth area is called the input area. This area is used to acquire input parameter(s) for the model. The fifth area is used to display intermediate or final result(s) of the particular model. The sixth area has a few buttons to help the user and to produce the output(s) of the model (or step). For some models, this area also has buttons to allow creation of a table of output values of the model as a function of the range of the selected input parameter. The following figures show the run of the CCIR rain attenuation model included in the database software.

6.0 Future of the Propagation Models Database

From the inception of the idea of Propagation Database till present, Microsoft Excel has been the underlying software. The reason for adopting Excel was that it truly offered unique capabilities of charting and scientific functionality. However, Excel has some drawbacks such as the slow execution of the program, the large memory requirement, and the need to own the Excel software by the users. Another disadvantage Excel entails is that whenever a newer version of Excel is released, such as Excel 5.0, it may not be fully compatible with the older versions such as Excel 4.0. This makes it difficult, if not impossible, for programmers to develop a long-term program. Having taken all these disadvantages into consideration, it was decided that future versions of the database shall be written in the 'C' language because this language offers some attractive qualities such as faster execution, efficient use of computer memory, and complete independence from the compiler software once the program is compiled.

7.0 Conclusion

A database of various propagation phenomena models that can be used by telecommunications systems engineers to obtain parameter values for systems design is presented. This is an easy-to-use tool and is currently available for either a PC using Excel.

software under Windows environment or a Macintosh using Excel software for Macintosh. All the steps necessary to use the software are easy and many times self explanatory, however, following is a sample run of the CCIR rain attenuation model.

A Sample Run of the CCIR Rain Attenuation Model

The following pages show a sample run of the CCIR model, which contains 6 steps:

Step 1: Calculates h_R , the effective rain height in kilometers.

The model used for the effective rain height, h_R , is as follows:

$$h_R = 3.0 + 0.028 * \Phi \quad 0 \leq \Phi < 36^\circ$$

$$h_R = 4.0 - 0.075 * (\Phi - 36) \quad \Phi \geq 36^\circ$$

where

Φ is the station's latitude in degrees.

- Enter Φ (the station's latitude) in degrees, e.g., 30 degrees.
- Click the Output button to see h_R (the effective rain height).
- Click the Step 2 button to go to the next step.

The screenshot shows a software window titled "CCIR". Inside, it explains the model's purpose: "This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz. This model has 6 steps, each will appear in a separate dialog box".

Step 1 of 6:

<<< MODEL >>>
 Calculate the Effective Rain Height.
 If ($0 \leq \Phi < 36$) (deg)
 h_R (km):
 If ($\Phi \geq 36$) (deg)
 h_R (km):

<<< INPUT >>>
 Φ (deg):

<<< DEFINITION >>>
 Φ : Station's Latitude.
 h_R : Effective Rain Height.

<<< OUTPUT >>>
 h_R (km):

At the bottom, there are four buttons: "Reference", "Output", "Step 2", and "Close".

Step 2: Calculates L_S , the slant-path length below rain height in km.

The model used for the slant-path length, L_S , is as follows:

$$L_S = \frac{(h_R - h_S)}{\sin(\Theta)} \quad \Theta \geq 5^\circ$$

$$L_S = \frac{2(h_R - h_S)}{\left(\sin^2(\Theta) + \frac{2(h_R - h_S)}{R_e} \right)^{1/2} + \sin(\Theta)} \quad \Theta < 5^\circ$$

where

h_R is the effective rain height in kilometers.

h_S is the height mean sea level of the earth station in kilometers.

Θ is the elevation angle in degrees.

R_e is the modified earth radius (defaulted to 8500 km).

- h_R was computed in Step 1.
- Enter h_S (the height mean sea level of the earth station) e.g., 0.632 km.
- Enter Θ (the elevation angle) e.g., 14 degrees.
- Change R_e (the earth radius) if necessary.
- Click the Output button to see L_S (the slant-path length).
- Click Step 3 to go to the next step.

CCIR

This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz.
This model has 6 steps, each will appear in a separate dialog box

Step 2 of 6:

<<< MODEL >>>

Calculate Slant-path Length.
If (Theta >= 5) (deg). Ls (km):

 If (Theta < 5) (deg). Ls (km):

<<< DEFINITION >>>
 hR: Effective Rain Height
 hS: Height above mean sea level of the earth station.
 Theta: Elevation Angle
 Re: Modified Earth Radius (8500 Km)
 Ls: Slant-path length below rain height.

<<< INPUT >>>

hR (km):
 hS (km):
 Theta (deg):
 Re (km):

<<< OUTPUT >>>
 Ls (km):

Step 3: Calculates L_g , the horizontal projection of the slant-path length in kilometers.
The model used for the horizontal projection of the slant-path length, L_g , is

$$L_g = L_s \cos(\text{Theta})$$

where

L_s is the slant-path length below rain height in kilometers.

Theta is the elevation angle in degrees.

- No input is required for this step.
- Click the Output button to see L_g (the horizontal projection of the slant-path length).
- Click the Step 4 button to go to the next step.

CCIR

This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz.
This model has 6 steps, each will appear in a separate dialog box!

Step 3 of 6:

<<< MODEL >>>

Calculate Horizontal Projection of the slant-path length.

Lg (Km):

<<< INPUT >>>

Ls (km):

Theta (deg):

<<< DEFINITION >>>

Ls: Slant-path length below rain height.

Theta: Elevation Angle.

Lg: Horizontal Projection of the slant-path length.

Reference

Output

Step 4

Close

<<< OUTPUT >>>

Lg (Km):

Step 4: Obtains $R_{0.01}$ (dB), the rain intensity exceeded for 0.01% of an average year and calculates $r_{0.01}$, the reduction factor.

The model used for the reduction factor, $r_{0.01}$, is

$$r_{0.01} = \frac{1}{1 + L_g/L_o}, \quad L_o = 35 \exp(-0.015 R_{0.01})$$

where,

$R_{0.01}$ is the rain intensity exceeded for 0.01% of an average year in mm/hr.

$r_{0.01}$ is the reduction factor.

- Select the Rain Climatic Zone, such as K for this example.
- Click the Output button to see $r_{0.01}$ (the reduction factor).
- Click the Step 5 button to go to the next step.

CCIR

This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz.
This model has 6 steps, each will appear in a separate dialog box

Step 4 of 6:

<<< MODEL >>>

Obtaining the Rain Intensity, R0.01 (mm/hr), exceeded for 0.01% of an average year.

Calculate Reduction Factor, ro.01:

=1/(1+Lg/L0)

Where L0 is,

=35*EXP(-0.015*R0.01)

<<< DEFINITION >>>

R0.01: Rain Intensity exceeded for 0.01% of an average year.
ro.01: Reduction Factor.

<<< INPUT >>>

Select Rain Climatic Zone:

☐ A	☐ D	☐ G	☒ K	☐ N
☐ B	☐ E	☐ H	☐ L	☐ P
☐ C	☐ F	☐ J	☐ M	☐ Q

<<< OUTPUT >>>

R0.01 (mm/hr):

ro.01:

Reference

Output

Step 5

Close

Step 5: Calculates *GammaR*, the specific attenuation using the frequency-dependent coefficient in dB/km. The formula used to calculate *GammaR* is as follows:

$$GammaR = kR_{0.01}^{\alpha},$$

$$k = [k_H + k_V + (k_H - k_V)\cos^2(Theta)\cos(2Tau)] / 2$$

$$\alpha = [k_H\alpha_H + k_V\alpha_V + (k_V\alpha_H - k_H\alpha_V)\cos^2(Theta)\cos(2Tau)] / 2k$$

where

Theta is the elevation angle in degrees.

Tau is the polarization tilt angle in degrees.

k and α are coefficients taken from Reports of the CCIR, 1990. Table 1. Regression Coefficients for Estimating Specific Attenuation.

- Enter *Frequency*, e.g., 12.5 GHz.
- Select *Tau*, e.g., 45 degrees for circular polarization.
- Click the Output button to see *GammaR*.
- Click the Step 6 button to go to the next step.

CCIR

This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz.
This model has 6 steps, each will appear in a separate dialog box

Step 5 of 6:

<<< MODEL >>>

GammaR (dB/km):

<<< INPUT >>>

Frequency (GHz):

Theta (deg):

Tau (deg):

☐ 0 deg: vertical polarization

☒ 45 deg: circular polarization

☐ 90 deg: horizontal polarization

<<< DEFINITION >>>

GammaR: Specific Attenuation using the frequency-dependent coefficient.

Theta: Elevation angle.

Tau: Polarization tilt angle.

k and Alpha are coefficients taken from Table 1 - Regression coefficients for estimating specific attenuations of Reports of the CCIR, 1990.

Reference

Output

Step 6

Close

<<< OUTPUT >>>

GammaR (dB/km):

Step 6: Calculates $A_{0.01}$, the attenuation exceeded for 0.01% of an average year in decibels.

The formula used for the attenuation exceeded for an average year, $A_{0.01}$ is:

$$A_{0.01} = \text{GammaR} * L_s * r_{0.01}$$

where

GammaR is the specific attenuation using the frequency dependent coefficient in dB/km.

L_s is the slant-path length below rain height in kilometers.

$r_{0.01}$ is the reduction factor.

Click the Output button to see $A_{0.01}$ (the attenuation exceeded for 0.01% of an average year).

Click the "Other p (%)" button to find attenuation exceeded for other percentages of an average year (0.001 to 1.0 %).

CCIR

This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz.
This model has 6 steps, each will appear in a separate dialog box

Step 5 of 6:

<<< MODEL >>>
Calculate Attenuation Exceeded for an average year.

A0.01 (dB):

<<< INPUT >>>

<<< DEFINITION >>>
A0.01: Attenuation Exceeded for 0.01% of an average year.

<<< OUTPUT >>>
A0.01 (dB):

Click the 'Other p' button to find attenuation to be exceeded for other percentages of an average year, ranging from 0.001 to 1.0 %.

Reference

Output

Other p (%)

Close

This step also calculates attenuation exceeded for an average year for other percentages (0.001 - 1.0 %).

The formula used for p percent of the attenuation exceeded for an average year is as follows:

$$A_p = A_{0.01} * 0.12 * p^{-(0.546 + 0.043 \log(p))}$$

where

p is the percentage of the attenuation exceeded.

A_p is the attenuation exceeded for p percent.

$A_{0.01}$ is the attenuation exceeded for 0.01 percent.

- Enter the p (percentage) of an average year.
- Click the Output button to see A_p , attenuation of p percentage and ratio of $A_p / A_{0.01}$

CCIR

This Rain model is used to calculate the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz.

<<< MODEL >>> A(p) A(0.01) $=A0.01*(0.12*(p^{-(0.546+0.043*\text{LOG}(p))}))$	<<< INPUT >>> p (%): 0.1
<<< DEFINITION >>> p: Percentage of Attenuation Exceeded of an average yr. A(p): Attenuation Exceeded for p % of an average yr. A(0.01): Attenuation Exceeded for 0.01 % of an average yr.	<<< OUTPUT >>> A(p) (dB): 5.60 A(p) 0.38 A(0.01)

When the close button is clicked the following dialog box appears

Microsoft Excel

? Do you want to chart or create table?

- Click OK to see the response.

Chart:

☐ Rain Rate vs. Attenuation
 ☒ Frequency vs. Attenuation

- Select one of the options, e.g., the Frequency vs. Attenuation.
- Click OK.

Enter Frequency parameter (GHz):

Minimum Value:

Maximum Value:

Step Size:

OK

Cancel

- Enter the minimum, maximum and step values
- Click OK

A new worksheet will then be invoked to store all of the parameters used, the table, as well as the selected chart.

The 'Print' option is available after this step.

This ends the sample run of the CCIR model.